

1911

552 (6822)

THE PETROGRAPHY OF THE AURIFEROUS CON-
GLOMERATES OF THE WITWATERSRAND, WITH
NOTES ON SOME ASSOCIATED ROCKS, AND A
DISCUSSION OF THE ORIGIN OF THE GOLD,

BY

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DECLARATION.

I hereby declare that the following
thesis entitled "The Petrography of
the Auriferous Conglomerates of the
Witwatersrand with Notes on some As-
sociated Rocks and a Discussion of the
Origin of the Gold" is composed by my-
self, and is a record of research car-
ried out by myself.

The Petrography of the Auriferous Conglomerates of the Witwatersrand, with Notes on Some Associated Rocks and a Discussion of the Origin of the Gold.

by Robert B. Young M.A., B.Sc..

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INTRODUCTION.

Though since their discovery in 1885 the auriferous conglomerates or banket of the Witwatersrand have received a great deal of attention from geologists, no attempt had been made to subject these rocks to a detailed petrographical study till a few years ago, when the present writer undertook the task. The results of much of this work have already been published in the transactions of the Geological Society of South Africa.⁽¹⁾

The description that follows, while based upon these publications, contains a considerable amount of additional information.

The banket may be briefly described as a siliceous quartz conglomerate i.e. a conglomerate whose pebbles and matrix are mainly composed of quartz.

THE PEBBLES.

Size. The pebbles vary in size from that of a pea to that of a goose's egg, though occasionally much larger ones occur, with diameters as great as eight inches. The average size is not far from that of a pigeon's egg.

Shape.

The great majority of the large-sized pebbles are muffin-shaped i.e. rounded but approximating to flatness on one side (see Fig.4). Though this shape is also common among the smaller and more normal pebbles,

(1. Notes on the Auriferous Conglomerates of the Witwatersrand. Trans. Geol. Soc. of S.A. Vol. X pp. 17-30. Further Notes on the Auriferous Conglomerates of the Witwatersrand, with a Discussion of the Origin of the Gold. Trans. Geol. Soc. of S.A. Vol. XII. pp. 82-101.)

the proportion is much less. The other forms are approximately ellipsoidal and spherical or, though rounded, are quite irregular, while forms with plane parallel faces but rounded edges are common in the case of fine-grained quartzite pebbles which generally have a banded structure (see Figs. 1 and 3). The muffin-shaped pebbles must owe their forms in great part to their having been pushed along on one face, though, from the fact that they often lie with their flat surfaces uppermost it seems probable that with diminishing size their motion became partly rotatory. The flat forms are due to original banding in the rocks from which the pebbles were derived, and the consequent tendency to break into slab-like fragments whose movement would be a gliding one.

The pebbles have sometimes obviously suffered distortion during the mechanical disturbances which the Banket beds have undergone. This is frequently accompanied by the development of a well-marked fissure system. The pebbles of vein-quartz, which are generally well-rounded, are sometimes angular, even sharply so (see Fig. 1.). This may be due to any of various causes viz, fracture by impact with other pebbles during or not long before their final deposition, irregular replacement round their margins by chlorite or sericite, or irregular secondary enlargement, the latter two causes operating of course subsequent to the formation of the conglomerate beds. The great thickness (approximately two miles) near Johannesburg of the Lower Witwatersrand Series, on which the Conglomerate dealt with rest conformably, renders it highly improbable that these pebbles

owe their sharp angular forms to proximity to their source.

DISPOSITION.

The pebbles generally lie with their longer diameters arranged roughly parallel to the bedding. On rare occasions narrow patches of banket are found in which the majority of the pebbles are disposed at right angles to the normal position. Imbrication or shingling is very common, but the direction of this is not constant even within a small area. This is to be expected in a shallow water marine deposit, where the motion is not always in the same direction (see Fig.1.).

COMPOSITION.

The principal pebble constituent is vein-quartz. This may be white, black, mottled white & black, or blue in colour, or colourless. On making moderately thin sections (say 1.0 mm. thick) of black pebbles, they are frequently found to be composed of a mixture of black, white and colourless quartz, the black tint being due to patches and streaks of dark-coloured inclusions. It is common to find in the white or milky quartz a ramification of minute veinlets of colourless quartz. The blue variety of pebbles gives out a milky opalescent light, and is always small, about the size of a pea or small bean. It is consequently commonest in the small-pebble conglomerates i.e. the so-called "bastard reefs". Occasionally vein-quartz pebbles containing a considerable amount of tourmaline are met with. When the "reef" is oxidised in whole or in part a reddish tint is often given to the vein-quartz pebbles by iron oxides which have penetrated the cracks.

Next in frequency to vein-quartz pebbles come those

composed of very fine-grained quartzite, sometimes referred to as cherty pebbles. Under the microscope these are seen to consist of a fine mosaic of quartz, often containing minute magnetite or haematite inclusions. The alternation of layers in which the average diameters of the individuals making up the quartz mosaic are different, and the disposition of the inclusions frequently give these pebbles a banded structure more or less evident to the naked eye (see Fig.3). The colours which the various bands show vary much, being light to dark grey, white, black, light green or red. They are obviously fragments of the rock variously known in South Africa as quartz-haematite-magnetite rock, banded ironstone, and calico rock. This rock is especially frequent in the Swaziland system. As already mentioned, pebbles of this type, possessing a banded structure, occur in flat slab-like forms. Many, however, are without that structure and are probably fragments of the wider bands in the original rock. Such, owing to their homogeneous texture frequently occur in rounded forms. To this class belong the well-known "pink pebbles" which are mistakenly regarded by many miners as indicating a high gold content. All the fine-grained quartzite pebbles in the banket are especially liable to replacement by pyrite, and it would be difficult to find one that on close examination did not show evidence of this process. When the pebbles are homogeneous in texture the replacement takes place mostly round the margins, but in the banded varieties there is generally a well-marked preferential replacement of certain of the bands. Sometimes the pebbles are wholly replaced by pyrite, their original character being indicated only by their shape and the rows of inclusions, which may still persist. In the oxidised zone the fine-grained quartzite pebbles become milky white in colour and incoherent.

The pebbles of the type just described appear to vary in their characters from place to place along the "reef" and are probably the only clue that could be employed to distinguish between blanket specimens from different sections of the Rand. The differences lie in the colour, width, frequency and definiteness of the bands. In a limited area the various reefs may in many cases be distinguished from each other by the relative numbers of white and black vein-quartz pebbles or of fine-grained quartzite pebbles, but instances can be shown where a predominantly white-pebble reef changes within a very short distance to one in which black pebbles are numerous and conspicuous.

Coarse quartzite pebbles occur, but not so frequently in the Main Reef Series as in the Kimberley Reef Series, where they are common. They are always well-rounded and are often larger than the other pebbles among which they lie. They vary in colour from light to dark grey. The writer has met with one instance of a coarse quartzite pebble containing a large amount of tourmaline.

Pebbles composed almost entirely of tourmaline in the form of minute crystals are occasionally met with. These exhibit a striking resemblance to certain replacements by tourmaline of argillaceous and fine-grained igneous rocks (felsites) associated with the tin deposits of the Transvaal and may have had similar origin.

The only pebbles in the blanket to which an igneous origin can with some degree of certainty be assigned, resemble quartz-porphyry in their macroscopic characters. At some places they are quite common in the conglomerates. On microscopic examination they are found to consist of quartz phenocrysts imbedded in a microcrystalline groundmass of quartz and sericite. The phenocrysts resemble those of quartz-porphyrines and allied

rocks. They appear to have been corroded and contain numerous sometimes comparatively large fluid inclusions. The sericite occurs mainly as inclusion in the quartz of the matrix but also in patches. Rutile in minute crystals is common. The rock may very well have been a quartz-porphyry which has undergone silicification, the sericite being produced from the alteration of feldspar. A change corresponding to this has been brought about in certain portions of a highly feldspathic quartzite in the Lower Witwatersrand Series known as the Speckled Bed. (2).

ALTERATION.

Many of the pebbles of the banket have been affected by metasomatic processes; thus replacement by pyrite and other sulphides, and by chlorite and sericite are common. These and other changes which are not confined to the pebbles will be referred to later when dealing with the matrix. However, there are occasionally noticeable other alterations which are peculiar to the pebbles. Some of the vein-quartz pebbles show to the naked eye a differentiation between the marginal 2 or 3 mm. and the core. Macroscopically this may appear as a darkening or dulling of the outside shell contrasting with a white or a glassy interior. Such pebbles, when examined under the microscope, are seen to consist in the interior of a medium or coarse grained mosaic of differently oriented individuals, the normal structure of vein-quartz. The marginal portions, however, are built up of quartz individuals differing so slightly in orientation that between crossed nicols an effect is produced which may be described as an undulatory or dappled extinction. The writer

(2) R.B.Young. The Alteration of the Feldspars in the Feldspathic Quartzite underlying the Hospital Hill Slates. Trans. Geol. Soc. of S.A. Vol. X. pp. 62-64.

has observed another somewhat remarkable change in a white quartz pebble from the Randfontein Central G.M.. The pebble is elliptical in section and at first glance appears to be an ordinary vein-quartz pebble. On closer examination it is seen to contain numerous ellipsoidal bodies 2.0 mm. or more in diameter consisting of four or five concentric shells from which the surrounding quartz spreads out in radiate fashion. A thin section near the border of the pebble revealed that the concentric shells are composed of sericite with intervening shells of radiate quartz. In one case two of these bodies have come together, the outside shells coalescing, presenting in section a beautiful appearance resembling the arrangement of the coloured rings in the interference figure shown by a section perpendicular to the acute bisectrix of a biaxial mineral in convergent light. An examination of the border of the pebble shows clearly that the structure just described must have originated at some period after the pebble was imbedded in the surrounding matrix as some of the concentric bodies have been formed on the very margin of the pebble and penetrate into the matrix, which they partially inclose. The fact that the longer diameters of the concentric shells are all roughly parallel to the longer diameter of the pebble, and that this was probably parallel to the bedding of the banket bed and thus at right angles to the original direction of greatest pressure suggests that pressure if not one of the exciting causes was at least a controlling factor of the change. It must be kept in mind while considering this or other apparently rare phenomena presented by a study of a rock like the banket that their seeming rarity may frequently be due to difficulty of observation.

BODIES ERRONEOUSLY REGARDED AS PEBBLES.

"Pyrite pebbles" are sometimes referred to in literature on the banket. Becker (3) applies this term to the minute rounded grains of pyrite (av. diam. 0.1 mm.) that are common in the rock; but the name has been more often given to larger rounded bodies of pyrite, varying in size from that of small shot to that of a marble. However, it is not now seriously contended that these were actually deposited as pebbles in the banket, but it has been suggested that they are pseudomorphs after pebbles of quartz or iron oxide. Occasionally much larger bodies, several inches in diameter, sometimes composed mainly of pyrite and marcasite, at other times largely of chloritoid, occur and are regarded as pebbles by miners. The origin of all of these bodies will be considered later.

THE MATRIX.

The matrix of the banket varies both in colour and texture, exhibiting in the upper or oxidised zone ("free milling") different shades of yellow, brown and red, and being less coherent and more porous than in the lower unoxidised zone ("blue-bar") where it assumes various shades of grey. The colour of the "free-milling" is due to iron oxides, the residual products of the decomposition of pyrite, which is a prominent constituent of the unoxidised matrix. The varying tints are the result of varying degrees of hydration of the oxide. The loose texture, which is most pronounced at or near the surface, is due to the oxidation and partial removal of the pyrite as well as the partial solution of quartz. One result of this change of texture is that the "free-milling" breaks by preference round the pebbles rather than through them, (see Fig. 2.).

(3) Becker: Annual Report U.S.A. Geol. Survey. 1896-7 pp.166-167.

In the case of the "blue-bar" this occurs only where there is an exceptional amount of chlorite or sericite in the matrix. The colour of the blue-bar, though influenced by the presence of pyrite, is determined mainly by the amount of chlorite or of sericite in the rock, the former giving rise to the darker and the latter to the lighter shades of grey.

ALLOGENIC OR
PRIMARY CON-
STITUENTS OF
MATRIX.

The matrix of the blanket has undergone considerable metamorphism and there are good grounds for believing that certain of its primary constituents have entered into new mineral combinations, thus rendering their original nature very doubtful. Those minerals then that can be demonstrated with a greater or less degree of certainty to be of allogenic origin are naturally of comparatively stable composition. By far the most abundant of these, as might be expected from the nature of the pebbles, is quartz.

QUARTZ. This mineral has generally undergone a certain degree of recrystallisation and only exceptionally can the original outlines of the grains be definitely made out. Occasionally minute crystals of apatite are enclosed by the quartz. It may be inferred from the extensive exposures of granite intrusive in the Swaziland System on which the Witwatersrand System rests unconformably, that the quartz of the matrix was derived from granite as well as from those rocks which are represented in the blanket by pebbles.

ZIRCON.

Zircon is a fairly constant constituent of the blanket and can be observed in about twenty per cent. of microscopic sections of the rock. In each of these sections generally only one or two grains are present, but occasionally there are as many as a dozen. Frequently they occur in

well-formed crystals exhibiting prismatic and pyramidal faces. At other times they are quite irregular in form and fragmental in appearance. The crystals, too, occasionally show rounding of the edges. The average length of the crystals is about 0.2 mm., while their thickness is about two-thirds or one-half the length. They are transparent and vary in colour from almost colourless to pink, sometimes with a brownish tint. The crystals are occasionally conspicuously zonal in structure.

There is nothing to be observed in their occurrence such as the interference of any other mineral with their growth, which would make the assumption of an allogenic origin improbable. Instances frequently occur in which pyrite is moulded on zircon, demonstrating conclusively that in some cases at least the zircon was in the rock before the pyrite (see Fig. 21.). Occasionally chloritoid is found moulded on zircon, (see Fig. 18.).

Zircons are found in the quartzites associated with the banket, though apparently in much less quantity.

CHROMITE.

Chromite, though occurring in about twenty per cent of microscopic sections of the banket, was first recorded as a constituent of the banket by the present writer in 1909. In section the grains of chromite are often irregular and rounded in outline, but occasionally they are square or rectangular. Their diameter averages slightly under 0.2 mm., though in some instances it is over 0.3 mm. Occasionally the grains have the appearance of having been fractured in situ by the insinuation of secondary material (e.g., chlorite, quartz, pyrite) along cracks. They have

every appearance of being allogenetic in origin, their probable source being the ultrabasic rocks associated with the Swazi - land System.

In a few of the sections the grains of the chromite are numerous, but more commonly they do not number more than one or two. They are not confined to the banket of any one locality in the Rand nor to any one reef.

Chromite grains also occur in the banded pyritic quartzite, a rock frequently associated with the banket, and it was from specimens of this from the Meyer and Charlton G.M. that there was first isolated a sufficient quantity of the mineral to place its identity beyond doubt. The material isolated consisted of round and irregular grains with a few octahedra. The mineral exhibited the usual physical properties of chromite, and gave as well the blow-pipe tests, which were further confirmed by wet reactions.

It is significant that while chromite is found both in the banket and the pyritic layers of the pyritic quartzite, it does not appear to occur in the accompanying non-pyritic quartzites, nor in the non-pyritic layers between the pyritic bands in the pyritic quartzite. This strengthens the hypothesis that the bands represent what were originally layers of "black sands".

TOURMALINE.

As might be expected from the presence in the banket of pebbles composed entirely or in part of tourmaline, fragments of this mineral occur in the matrix of the rock. Tourmaline is however, more often clearly a secondary constituent and the detrital grains almost invariably show a later growth of the same mineral round their borders. On this account the detailed de-

scription of the tourmaline will be given in the section of the paper dealing with the authigenic constituents.

IRIDOSMINE.

Among the rare minerals associated with the banket, and doubtless of allogenic origin, is iridosmine. This mineral, is obtained from the crushed ore of the Du Preez Series at Rietfontein, but in quantities too small to be of commercial value. Up to the present it has never been observed in situ. It is got in flattened and rounded grains, and in tabular six-sided rhombohedral crystals, both averaging in diameter about 0.12 mm. In the crystals the basal and rhombohedral faces are distinct, the prism faces less so or absent. The basal cleavage is well marked, many of the grains being in the form of basal flakes, probably produced, in part at least, during the crushing of the rock. The colour varies from tin-white to steel-grey, and the lustre from splendid to dull. The hardness lies between 6 and 7. An impure sample of the mineral gave a specific gravity of 17.9. On testing for osmium, results were obtained which show that this element is present in considerable quantity. It seems not improbable that there are other minerals of the platinum-iron group mingled with the iridosmine.

DIAMONDS.

Two white diamonds are reported to have been found in banket on the Percy claims near Johannesburg.

THIGENIC OR
CONDARY CON-
ITUENTS OF
E MATRIX.

QUARTZ.

Among the authigenic or secondary, as among the allogenic constituents of the matrix, the most prominent is quartz. As the outlines of the primary quartz grains are seldom preserved, usually no clear distinction can be drawn between the two, nor is it possible to distinguish

between secondary quartz derived by a process of recrystallisation from detrital quartz and that which has been introduced from without. There can be little doubt that the matrix of the banket has passed through a stage occasionally met with in the Witwatersrand bankets themselves and more frequently seen in the conglomerates of the Black Reef Series rocks, which though closely resembling the former, are much younger and have suffered less dynamical disturbance, viz, enlargement of the original grains, with preservation of their outlines, to form a compact rock. In the case of some of the quartz its secondary origin is clearly indicated by the forms in which it occurs. Thus patches of fine-grained quartz mosaics enclosing scattered grains of chlorite or of sericite are common. Again quartz occurs in columnar and fibrous forms. The former kind is most often found bordering crystals of pyrite or forming veinlets in the same mineral. The fibrous quartz is somewhat peculiar and differs from the columnar type in that the individuals are thinner compared with their length, have exceedingly irregular forms in transverse section, and are frequently elongated perpendicular to the vertical axis, thus simulating an optically negative mineral. The fibres are generally slightly bent and enclose between them occasional flakes of sericite. This form of quartz frequently forms concavo-convex growths at the acute terminations of certain flat ellipsoidal nodules of marcasite or pyrite, which are sometimes a feature of the banket, or occurs as a secondary enlargement of quartz pebbles, (see Figs. 6, 13, & 15.).

CHLORITOID.

Chloritoid is a very common mineral not only in

the banket but in some of the rocks associated with it e.g., the banded pyritic quartzite; the dark-coloured slatey-locking rock frequently found underlying the Main Reef Leader; and much sheared portions of quartzites or of basic igneous intrusions. In the banket it occurs in small flat plates, which in thin sections are colourless or have a faint greenish tint. In the latter case it may exhibit a slight pleochroism. Between crossed nicols the characteristic twinning of the mineral is revealed. It is frequently found in isolated crystals, but also commonly in clumps of crystals, often with a rosette-like arrangement. Its relative abundance from place to place is a measure of the metamorphism which the rock has undergone. The determination of its relations to the other minerals of the banket is of the highest importance in unravelling the sequence of mineralogical changes in the rock. It is evident from an examination of thin sections of the banket that the growth of the chloritoid has been mainly at the expense of the quartz which it replaces, especially where the quartz individuals are small. On the other hand the chloritoid crystals have been effectively obstructed by such minerals as pyrite and zircon. The relation of the chloritoid to the pyrite and other sulphides present affords an easy means of determining in any particular case whether these minerals were introduced into the banket earlier or later than the chloritoid.

The chloritoid is subject to alteration. The most general change observable is a partial replacement by quartz which contains some scattered flakes of chlorite or sericite. As a result the chloritoid crystals become ragged and lose more or less of their crystalline outlines. It is not uncommon to find a crystal broken up into three or more ragged segments separated by quartz but retaining their original optical orientation, and showing traces of the crystal out-

lines still in line. Sometimes the position of the original crystal boundaries are partially indicated in the secondary quartz by broken lines of very minute inclusions. In other cases the broken outlines of the chloritoid are evidently due to obstructions in the path of their growth. In many portions of the banket no further alteration besides replacement by quartz can be detected. Frequently, however, another and generally later change has occurred and the chloritoid, in most cases already partially replaced by quartz has been altered to chlorite and sometimes sericite, with both of which there may be a slight admixture of quartz.

There is a clear relation between the relative abundance of chloritoid and of a portion of the pyrite (afterwards described as 'the second generation of pyrite') in the banket. Generally speaking where chloritoid or its alteration products are plentiful, there this pyrite is abundant also. This is due to the circumstance that the production of much chloritoid in the rock has been accompanied by other changes such as the recrystallisation of the quartz to form fine-grained mosaics, which facilitated the introduction and action of solutions from which pyrite was precipitated at the expense of quartz (see Figs. 8, 9, 14, 18, 19 & 20.).

Irregularly shaped bodies with rounded outlines several inches in longest diameter, composed in great part of chloritoid but also containing quartz, chlorite, and pyrite are occasionally met with in the banket and associated quartzites. They have a concentric structure, the various shells being distinguished mainly by the different proportions contained of the minerals already mentioned. It is possible that these bodies are simply metamorphosed argillaceous concretions.

PYRITE,

Pyrite is by far the commonest sulphide in the bank-

ket and is present in considerable quantity. It occurs in several distinct forms viz., rounded grains, grains of irregular form, well-formed crystals, irregular crystalline aggregates, and spherical, discoidal, and irregularly rounded bodies.

The rounded grains are of common occurrence and average in diameter about 0.1 mm. They formed part of the banket before the chloritoid appeared, as is demonstrated by the moulding of the latter on the pyrite. These bodies are referred to by Becker (4), as "pyrite pebbles" and are considered by him to be of detrital origin, not only on account of their form but also because of an alteration round their borders to ferric oxide. This latter observation has never been confirmed and not one instance of oxidation of these pyrite grains has been detected by the present writer in the hundreds of microscopic sections of the banket which he has examined, except of course those from the oxidised zone, where the oxidation of pyrite is general. It is possible that the material which Becker took to be ferric oxide was in reality the fine-grained aggregates of rutile which are of frequent occurrence in the banket and which occasionally border pyrite granules.

Gregory (5), who agrees with Becker in assigning an alluvial origin to the gold in the banket, is unable to accept the views of the latter regarding the pyrite, and it seems highly improbable that so brittle and easily oxidised a mineral as pyrite could have been deposited broadcast as rounded and unaltered grains in a shallow-water marine deposit. To the writer the hypothesis that the rounded form

(4) Op.cit. pp. 166-167.

(5) Bulletin No.35. Inst. Min.& Metal., London (1907).

of these grains is due to their being pseudomorphous after some other detrital mineral e.g. some oxide of iron, seems more plausible. (see Figs. 17 & 18.).

The pyrite occurring in the other forms already mentioned, which constitute a very considerable proportion of the pyrite in the banket, cannot possibly be detrital. The moulding of this pyrite on zircon, probably a primary constituent of the banket, and on chloritoid, a late secondary mineral, proves this conclusively, though in most cases the form of the pyrite is sufficient to do so.

Well-formed crystals of pyrite; cubes, pyritohedra, and various combinations of the simple forms, are a conspicuous feature of many portions of the banket. These occur not only ⁱⁿ the matrix but also encroaching on the borders of pebbles & within the pebbles themselves, more especially those consisting of fine-grained quartzite. Pyrite crystals are most abundant in the neighbourhood of basic intrusions where they are generally associated with a large amount of chloritoid. In the quartzites associated with the banket numerous and fairly large cubes of pyrite are sometimes met with, in some cases as much as 2.0 cm. in diameter. The writer has observed one instance in which cubes and irregular patches of pyrite had been dissolved out of a compact quartzite and the cavities thus produced lined with pyrite crystals or filled with pyrrhotite, chalcopyrite, and pyrite. (see Figs. 21 & 22).

Irregular patches of pyrite are sometimes a conspicuous macroscopic feature of the banket. Their longest diameters do not generally exceed 1.5 cm. and are frequently not more than half this length. Under the microscope they are seen to consist of aggregates of crystals usually inclosing abundant fresh chloritoid crystals. Where the crystals

are not closely packed together they are frequently linked by thin veins of pyrite which run along irregular cracks in the quartz grains or round their borders (see Figs. 7, 9 & 19).

Spherical, discoidal and irregularly rounded bodies of pyrite and marcasite occur in some portions of the banket, often in great numbers. Their diameters may attain a length of 2.0 cm. but generally they are less than 1.0 cm. The spherical type, sometimes known as "buckshot pyrite", is best seen in the beds of the Du Preez Series at Rietfontein. They average about 2.0 mm., in diameter. Their surface has a hackly appearance due to projecting corners and edges of pyrite crystals, while internally a radially fibrous structure is common. They sometimes inclose crystals of chloritoid. Some of the nodules are plastered or gilded over with coarse gold. The discoidal type is best seen in the rocks of the Battery of Kimberley Reef Series on the West Rand. They vary in diameter from 1.0 mm., to nearly 2.0 cm. Their surface is generally smooth, but is sometimes rough, like that of the "buckshot pyrite". The fracture has commonly a finely granular appearance with a dull lustre, but that of some of the nodules reveals a coarse texture and has a bright lustre. Many of the nodules when examined with the naked eye, appear to be composed entirely of pyrite or marcasite, while others evidently enclose particles of quartz and other minerals. A radially fibrous structure is much less common than in the case of the "buckshot pyrite". They are frequently traversed by veinlets of fibrous quartz which evidently run along planes of fracture. When examined in microscopic sections they are seen to be obviously of late secondary origin, replacing the quartz of the matrix and the pebbles. They enclose wholly or partially numerous crystals of chloritoid. They have generally a border of the

fibrous quartz already described, and this is especially developed along the acute edges of the nodules. Occasionally between the fibrous quartz and the compact pyritic core is a zone composed mainly of pyrite and partially replaced grains of quartz. One specimen of banket from the Battery Reef Series which the writer has examined contains a large dark coloured quartzite pebble, which is broken through, exposing to view a pyrite nodule, in section 1.7 cm., by 1.0 cm., embedded mostly in the pebble but partly in the surrounding matrix. (see Figs. 5, 6, 13 & 16.).

The forms of irregularly rounded nodules frequently suggest that they owe their shape to attrition or that they are pseudomorphous after pebbles of quartz or some other substance, but some of these on being broken reveal internally a radially fibrous structure.

That some of the nodular bodies consist partially at least of marcasite is shown by their comparatively rapid alteration on the outside to ferrous sulphate after long exposure.

The question of the origin of the rounded forms of pyrite and marcasite just described has been much discussed, Mr. F. White (6), and Messrs. Hatch and Corstorphine (7), regard them as concretions, Mr. B. Horwood, (8), as pseudomorphs after quartz pebbles, Professor Gregory (9), as pseudomorphs after ironstone pebbles, while others look upon them as rolled pebbles. From the feature above described there now remains no doubt that at least the great majority of the bodies are replacements of quartz both of the matrix and of the pebbles of the banket, and that their forms are

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- (6) Trans. Geol. Soc. S.A., Vol. IV. (1899), pp. 55-56.
(7) Trans. Geo. Soc. S.A., Vol. VII. (1905), pp. 140-141.
(8) Quart. Jour. Geol. Soc. London, Vol. LXIII. (1907), p. LXX.
(9) Op. cit. p. 36.

not pseudomorphous but the direct result of the mode and conditions of their growth.

There occasionally occur in the banket rounded bodies mainly composed of pyrite and marcasite, of larger size, being several inches in diameter. The marcasite is sometimes present in the form of numerous rudely spherical nodules, with a coarse radiate structure. With the sulphides, silica in the form of chalcedony and quartz mosaics and veins is mingled, as well as some chlorite. These bodies resemble in size and form the chloritoid nodules already described and may represent a further stage in the alteration of argillaceous concretions.

PYRRHOTITE.

Pyrrhotite is frequently met with in the banket and associated rocks. Sometimes it is a very conspicuous macroscopic constituent of the banket quite obscuring the pyrite present. More often it occurs as scattered amoeba-like patches about 3 mm. in diameter but sometimes as much as 2.0 cm. A microscopic examination reveals that it is always a replacement of the quartz of the matrix and pebbles and is frequently later in origin than the pyrite, which it may envelope. The mineral most commonly associated with it is chlorite, often in large quantity (see Fig.10).

OTHER SULPHIDES.

The other sulphides met with in the rock are chalcopyrite, arsenopyrite, sphalerite and galena. The mode of occurrence of these minerals shows conclusively that they are late replacements of quartz. It is not always possible to identify with any certainty the grey coloured sulphides apparent and sometimes common in microscopic sections. In several instances in which the writer has gone to the trouble

of isolating and testing these, they have been proved to be arsenopyrite which would thus appear to be a frequent constituent. Mr. A. F. Cross (10), has recorded the occurrence of cobaltite in the banket. Sphalerite is especially common in the rock mined in the Geduld G.M.

There is often a clear connection between basic intrusions and the abundance and variety of sulphides in the banket and associated quartzites, the sulphides, including pyrite, increasing in quantity with proximity to the dykes. (see Fig. 22.).

CHLORITE.

Members of the chlorite group are abundant in the banket and associated rocks. Some of this is obviously an alteration product of chloritoid but the bulk of the chlorite is very clearly related to the basic intrusions. The presence of abundant chlorite in any portion of the banket is so clear and invariable an indication of the proximity of these igneous rocks, that they can safely be predicated at a distance, varying naturally with the thickness of the dyke, in the course of "driving" etc., in the mines. This chlorite occurs as a replacement of the quartz of the matrix and the pebbles. The matrix is, as one would expect, attacked most, but within a few feet of the intrusions the pebbles may frequently be seen to be largely replaced by chlorite. The second generation of pyrite as well as pyrrhotite and the other sulphides, when present in large quantity, are always associated with much chlorite, thus indicating a common source. Chlorite is also frequently an asso -

(10) Proceedings Chem. & Metal. Soc. of S.A. Vol.V. p.135.

ciate of coarse gold in the banket. (see Figs. 12 & 24.).

MUSCOVITE.

Muscovite, sometimes in fairly large flakes, but more often as aggregates of sericite, is universally present in the banket but in very variable amounts. At places the sericitisation of the quartz is as conspicuous as the chloritisation is elsewhere, the matrix and pebbles being both considerable replaced. Under these circumstances it is not unusual to find coarse gold associated with the sericite, (see Figs. 24, 27, & 28.).

RUTILE.

Both in the matrix of the banket and in the pyritic bands of the pyritic quartzite, aggregates of a yellow, brown, or grey material appearing opaque or almost so when not highly magnified are frequent, and, in many sections, very conspicuous when viewed by reflected light. In transmitted light they may be easily mistaken for pyrite or some other opaque mineral. The cores of these aggregates are generally darker in colour and coarser than the marginal layer. When highly magnified it is seen to be translucent and doubly refracting, and the marginal portion can sometimes be made out to be composed of a loose aggregate of minute rutile needles, about 0.01 mm., in length. Sometimes a little secondary quartz lies between the outer layer and the core. The patches have an average diameter of about 0.5 mm., and are generally moulded on grains of quartz, pyrite, or other minerals, or lie embedded in fine mosaics of secondary quartz.

Grains of this material, on being isolated, were found to resemble rutile in lustre, colour, and fracture. In some cases the marginal layers of these isolated grains broke away from the core, but both core and crust gave strong

titanium reactions. Professor Gregory (11), refers to this material under the general term "leucoxene", and it seems probable that it consists throughout of rutile. The patches seem to be almost entirely confined to pyritic rock, and not scattered throughout the associated quartzites barren of pyrite. This makes it quite conceivable that among the detrital matter originally deposited among the pebbles of the blanket and in the layers now represented by pyrite bands in some of the quartzites, some heavy titaniferous mineral was included (12). There can be no doubt that the rutile, as we now find it, is of secondary origin.

Besides the aggregates just described, similar material, generally light in colour, is very commonly found running in thin layers between the grains of quartz and other minerals, and is frequently seen disseminated in this manner through fine mosaics of secondary quartz. In such cases, it can generally be made out by careful examination to consist of minute rutile needles.

Small clusters of distinct rutile needles, as well as isolated individuals and characteristic geniculate twins, can be detected in almost any microscopic section of the normal blanket.

TOURMALINE.

In about fifteen per cent of the writer's microscopic sections of the blanket one or more grains of tourmaline may be observed. The outlines of some of these suggest that they are of clastic origin and this is further supported by the presence of pebbles of tourmaline, as already noted. In the majority of cases, however, the tourmaline is clearly

(11) Op.cit. p.30.

(12) Vide Schmeisser: "Vorkommen und Gewinnung der nutzbaren Mineralien in der Südafrikanischen Republik." Berlin (1894), p.49.

of secondary origin and from the borders of what are apparently fragmentary grains, fine needles of secondary tourmaline sometimes project into the surrounding matrix. The grains of tourmaline vary considerably in size, but their longest diameters seldom exceed 0.5 mm. In colour they are generally brown or green in the centre and blue round the margin, the finer needles however being invariably blue. Sometimes the grains consist of more than one individual, the boundaries between the different individuals being occasionally blue. That much of the tourmaline is secondary is evident, not only from the form, which is that of a natural growth of the mineral in situ, but also frequently from the moulding of the tourmaline on quartz grains. Sometimes the occurrence consists of a cluster of close or scattered fine needles lying in the normal matrix of the rock.

Tourmaline grains are also found in the banded pyritic quartzite.

The close association of secondary tourmaline and coarse gold is sometimes very apparent (see Figs, 23, 24, & 26).

An occurrence of tourmaline, apparently quite exceptional on the Rand, can be seen at the Croesus G.M. in a drive on the 8th level. There, over a few feet, the quartzite and banket exposed on the two walls and floor are traversed by a reticulating system of quartz and tourmaline veins, giving the rocks a brecciated appearance. The veins vary in thickness from an inch downwards, and at places are of quartz only, but generally they contain tourmaline as well, most often massed in the centre. Occasionally quartz is entirely absent from the veins or in very small proportion to the tourmaline. The tourmaline is generally in the form of a hard mass of fine needles firmly felted together, but it also occurs as loose friable aggregates of needles.

Under the microscope the tourmaline needles are

seen to be light blue or brown, sometimes blue at one extremity and brown at the other. In the closely felted masses they vary in length from about 0.5 mm., downwards, though the more scattered crystals are sometimes over a millimeter in length. At the contact of the veins with the quartzite and banket, the tourmaline can be seen replacing these rocks, passing into and around the quartz grains in radiating bundles of needles. In the interior of the rocks penetrated by the veins occur scattered patches of radiating tourmaline needles. A little pyrrhotite is present.

This occurrence in the Croesus G.M. is four or five hundred feet from the nearest dyke intersected in the mine workings.

CALCITE.

In the Meyer and Charlton Gold Mine there is a very large body of banket and quartzite, in which the quartz has been wholly or partially replaced by calcite, the pyrite remaining unaltered. A brief note on this occurrence was written by Dr. J. Kuntz (13), in 1903. While examining this portion of the mine some years ago, the writer noticed in a portion of the "reef" outside the calcified body, calcification in progress for about an inch on either side of narrow fissures, from which water was issuing. Dr. Kuntz refers in his paper to a "break" from which a more extensive calcification had proceeded. There is little doubt that the whole of the calcified rock has been produced in the manner indicated by these instances.

Thin sections of this rock, microscopically exam-

(13) Trans. Geo. Soc. S.A., Vol. VI., pt. IV., p.14.

ined, reveal that the replacement of the quartz by calcite is quite irregular. The alteration of the pebbles naturally proceeds from without inwards, and more rapidly along cracks than elsewhere. The replacing calcite is coarse-grained, and shows frequent and well-marked lamellar twinning. Several individuals of calcite may replace a single individual of quartz, and on the other hand, several individual of quartz may be replaced by a single individual of calcite. In the replacement of the matrix the calcite grains formed are generally smaller than in the pebbles. In sections which show remnants of unaltered quartz within the pebbles no quartz appears in the matrix.

The grains of unaltered pyrite are sometimes partially or wholly enclosed in calcite, but more generally they are surrounded by a mixture of chlorite and sericite. The latter minerals are abundant in the altered matrix, frequently occurring in large irregular patches. Occasional grains of pinkish zircon occur associated with the pyrite and the hydrous silicates just mentioned. (see Fig.11).

A section of calcified banded pyritic quartzite which I examined resembles more or less the matrix of the altered blanket. In the pyritic bands there is an abundance of chlorite, with a little sericite, and an occasional grain of zircon. In the non-pyritic portions large individuals of calcite have each replaced groups of quartz grains, the original outlines of which are still roughly indicated by lines of chlorite enclosed in the calcite.

The calcification of the blanket has had no appreciable effect on the gold content. A slight replacement of quartz by calcite, and more rarely by dolomite, is occasionally observable in blanket from other localities than the above.

CARBON.

The occurrence of this substance in the auriferous rocks of the Witwatersrand and the Klerksdorp area has already attracted considerable attention.

The specimens on which the following description is based were got from the following mines:- Rietfontein A.G.M., Crown Deep G.M., N.Randfontein G.M., Van Ryn G.M., Cason G.M., Simmer & Jack G.M., May Consolidated G.M., Meyer and Charlton G.M., Bon Accord G.M. (Greylingstad), and the Buffelsdoorn G.M. (Klerksdorp).

The form in which the carbon commonly occurs is that of small, black, opaque nodular grains having a somewhat warty dull outer surface, but lustrous on the surface of fracture and ranging in diameter from one millimeter downwards. Sometimes, as in the Buffelsdoorn specimens, the nodular grains as they increase in number blend together into vein-like compact masses which are anthracitic in appearance. The veins are sometimes over half an inch thick. Still another form is met with in Rietfontein, where it occurs not only in nodular grains, but also in veinlets with a columnar structure, the columns being perpendicular to the walls of the veinlets. In one of my specimens the thickness of the veinlets varies from 2.0 mm. to 1.5 mm., while the columns are about 0.5 mm. thick and of variable form in cross section. Between the columns there are generally present very thin films of sericite.

The most remarkable feature in the occurrence of this substance is its replacement of primary quartz. Apparent instances of this are frequently to be observed in the quartzitic matrix of the banket and in the associated quartzites, but the possibility in such cases of mistaking secondary for primary quartz renders these observations

doubtful. The writer however has obtained specimens of banket from the Bon Accord G.M., and the Meyer & Charlton G.M., in which the carbon occurs in the pebbles as well as the matrix. In the specimens from the former locality the carbon occurs abundantly both in fine-grained striped quartzite pebbles and in the vein-quartz pebbles as small nodular particles, similar to those in the matrix. Cracks are visible in the pebbles and the maximum replacement is in the neighbourhood of these, showing that they formed the avenues along which the medium from the carbon was precipitated entered the pebbles. In the case of the fine-grained quartzite pebbles a preference is shown by the carbon as by pyrite for certain band. In the same specimen the carbon also occurs as veinlets lying along irregular cracks.

On the surface of the carbon nodules there very frequently lie films of gold, and this metal in films and hackly particles is also present, sometimes in still larger quantity, in the enclosing material, in close proximity to the carbon. In the columnar variety, already described, the gold is present in the sericitic partings between the columns, as well as on the surface of the columns. Sometimes films of gold may be observed in the secondary quartz in the neighbourhood of the carbon grains. In the veins in the Buffelsdoorn G.M., pyrite in films and granules, and sometimes gold, are visible.

With regards to the composition of the substance the writer obtained from Dr. James Moir, Chemist to the Mines Department, Transvaal, the following report on an impure specimen occurring as a vein in the Buffelsdoorn G.M.

"On submitting to destructive distillation, only water containing H_2S and suspended sulphur was obtained and the gases were CO and CS_2 . Only a trace of sulphuric acid in

and of arsenic was obtained."

" The following is the approximate composition of the sample as given by analysis:-

Carbon	34.2%
Silica, insoluble	23.1%
Iron pyrites	20.8%
Aluminium Silicate ash	10.0%
Combined water	<u>11.9%</u>
	<u>100.0%</u>

The carbon is remarkably resistant to heat, but is not graphitic. Lime and magnesia are practically absent from the ash."

Regarding another similar sample he writes, "Extraction with organic solvents gave only a very small trace soluble viz. 0.22%, which was found to be sulphur. There is no bituminous or hydrocarbon constituent. On heating no certain evidence of tar or coal-gas was obtained." In this sample he found traces of cobalt arsenide, titanio acid and gold.

The Hardness of the carbon lies between 2 & 3 and the Specific Gravity is about 1.5.

GOLD.

Gold visible to the naked eye is comparatively rare in the banket taking it as a whole, though in certain localities rock showing it is easily found. The coarsest gold is generally found in oxidised banket, where it may represent in part a secondary enrichment. In a specimen of "free milling" from the Wemmer G.M. taken from a depth of 100 feet, in which the pyrite has been replaced by a reddish-brown iron oxide or entirely or partially dissolved away leaving moulds, the gold is seen occurring in small

hackly grains and larger films, the latter being sometimes as much as 4 mm. in diameter. The smaller grains are congregated in the neighbourhood of the moulds and pseudomorphs after pyrite, occasionally within them, but oftener in the surrounding rather loose quartzitic matrix. The films are obviously not alluvial flakes, but have been precipitated along cracks, sometimes in the pebbles. Some of the smaller flakes are dendritic in form.

Films of gold may be observed sometimes in the non-oxidised banket, but their form can always be accounted for by precipitation in situ. The nodular marcasite or pyrite ("buckshot") found in the Du Preez Series and elsewhere is sometimes coated with films of gold, and, as stated elsewhere, much of the gold associated with carbon, the former presumably precipitated through the reducing action of carbon or hydrocarbons, is in the form of films or flakes. The writer has never observed in the banket any undoubted alluvial flakes of gold, and what has been described as such is merely precipitated films deriving their forms from their surrounding.

In microscopic sections of the unaltered banket the gold is seen to occur generally in irregular grains, the forms of which resemble those in which gold occurs in quartz veins. Sometimes they are small hackly particles and at other times their different dimensions are very unequal, and they may thin and thicken out very irregularly, occasionally assuming quite fantastic forms.

The gold, as is well known, occurs almost exclusively in the matrix of the banket, but occasionally it is found in the pebbles. In one case of this that the writer has studied in the unoxidised banket, the pebble was composed of a very fine quartz mosaic, i.e., it was one of those pebbles generally designated slaty or cherty in descriptions

of the banket. The gold ran along a crack in the pebble, and as the matrix of the rock contained an abundance of gold obviously precipitated in situ and there was evident a certain amount of replacement of both pebble and matrix by pyrite, there could be little hesitation in concluding that the gold entered the pebble along a crack probably at the same period as it was being precipitated in the surrounding matrix.

In a piece of banket from the Cason G.M. the writer came on a tourmaline pebble with a considerable quantity of coarse gold lying along a parallel series of fine cracks. The matrix immediately adjoining the pebble contained crystals of secondary tourmaline associated with much coarse gold.

Occasionally distinct well formed crystals of gold are found in the quartz of the matrix of the banket. Their dimensions vary from 0.01 mm. to 0.04 mm. Some of these are fairly symmetrical octahedra which have combined with them other very minute faces too obscure for satisfactory determination. In the case of other crystals, the forms are difficult to determine not only on account of their small size, but also because of their complexity and distortion. Several crystals may occur within a very small radius. They are generally associated with a little chlorite, and in one such occurrence a stringer of chlorite may be observed leading continuously from the outside of the grain to the octahedron of gold in its interior. In this instance larger irregular grains of gold lie round the outside of the quartz grain. Needles of rutile, as well as sagenitic and granular aggregates of the same mineral are present in unusual quantity, and also needles of secondary tourmaline.

In several specimens of banket much gold is asso-

ciated with a markedly unusual quantity of tourmaline. In these cases the gold is close to, or in actual contact with and partly surrounding the tourmaline.

Muscovite in sericite aggregates or in large flakes is always present in banket showing coarse gold, and in some cases it is in large quantity, replacing to a marked degree the quartz both of matrix and the pebbles. Flakes of a mica with a slight green or brown tint, and pleochroic, are not uncommon. Chlorite is occasionally present in large amount, but is frequently subordinate to muscovite, and may be present in quite negligible quantity. Metasomatic replacement of quartz by pyrite is a common feature of this class of rock

The immediate circumstances under which gold occurs in the unoxidised banket and associated quartzites may be summarised as follows:-

(a) As irregular grains.

- (1) In quartz grains, near the margin or in cracks, or between two crystalline individuals. In such cases it is occasionally accompanied by chlorite.
- (2) Between quartz grains to the exclusion of any other mineral.
- (3) In secondary quartz mosaics which frequently contain an admixture of sericite.
- (4) In contact or intergrown with pyrite.
- (5) In bodies of sericite.
- (6) In and surrounding patches of rutile.
- (7) In bodies of chlorite.
- (8) In or associated with carbon, and marcasite nodules.
- (9) In contact with or partially surrounding tourmaline.
- (10) In contact or intergrown with arsenopyrite.

(b) As crystals.

- (1) In quartz grains generally with some associated chlorite.
(see Figs. 24, 25, 26 & 27.).

GOLD TELLURIDE.

Accompanying the iridosmine from Rietfontein already described, the writer found on microscopic examination, minute clumps of crystals of an opaque brass-yellow mineral having a bright metallic lustre. The longest diameters of the largest crystal clumps were about 0.3 mm., the crystals themselves being generally very minute. The appearance of the clumps suggests that they occur as minute druses in the rock.

The mineral easily breaks up on pressure to hackly fragments of the same brass colour as the crystal faces. On heating it to redness there are left slightly spongy pseudomorphs of a light-yellow gold. The quantity of the mineral obtained was too minute for satisfactory analysis, but to judge from the properties mentioned, it is probable that it is a telluride of gold.

SOLUTION OF

QUARTZ IN THE BANKET.

A good instance of solution of quartz in the blanket without replacement was met with along a fault plane in the Robinson Deep G.M. on the 2300 feet Level stope. The quartz of the pebbles and matrix alike had been partially dissolved. The process of solution had been most rapid along the surfaces of contact of quartz grains. The pebbles show beautifully etched surfaces and in places a highly porous structure. The matrix where it has been most exposed to the action of the solvent has been reduced to a feebly coherent sandstone in which the pyrite grains are laid bare. The latter mineral shows no signs of alteration.

THE AURIFEROUS

BANDED PYRITIC QUARTZITE.

This rock has already been described by others, including Dr. Voit (14). It occurs in lenticular bodies of varying dimensions. Where sections of the thicker portions

(14) "The Genesis of Rand Gold." The Mining Journal
(London) 5th Sept. 1908.

of these lenticles are exposed to view, the pyritic bands generally show a very perfect and even bedding, even very thin layers persisting for some distance. At places quartz pebbles make their appearance and the pyritic quartzite merges into the matrix of the banket. Round the edges of the lenticles, where the pyritic bands rapidly thin out, they lose their evenness of bedding, and by ^{the} course they take show up beautifully the current bedding of the quartzite. Microscopic sections of the pyritic bands reveal that they are identical in composition with the matrix of the banket and might be described as banket without the pebbles. Chromite is common. (see Fig. 20.).

VEINS IN THE

MAIN REEF SERIES.

Quartz veins both with and across the bedding are common throughout the Witwatersrand System and are frequently met with in the mines on the Main Reef Series. Usually they occur in a haphazard fashion, though it is not uncommon to find them associated with igneous intrusions and faults. They generally consist of quartz alone, or with only a negligible quantity of other minerals. Sometimes other constituents are present in considerable amount. Of silicates the commonest is talc, which usually occurs as a border on both sides of the veins. A splendid example of this is seen in the Luipaards Vlei Estate G.M. The talc is there a beautiful blue variety with well-defined columnar structure, and may be several inches thick. Kyanite may occur embedded in the talc as in the Roodepoort United G.M., where it forms radiating aggregates of long bladed somewhat decomposed crystals. The veins containing tourmaline in the Croesus G.M. have already been described. Another silicate is epidote, which may be associated with calcite as in the

Simmer Deep G.M.

Of sulphides occurring in the veins, the commonest are pyrite, both massive and in definite crystals, and chalcopryite, usually massive. Less frequently are found pyrrhotite, galena, sphalerite and arsenopyrite.

In a vein in the May Consolidated G.M. sphalerite, galena, and chalcopryite are found closely associated. In another vein in the same mine massive chalcopryite sometimes showing a very distinct cleavage and altering to covellite and malachite is got.

Gold is also found in the veins, and occasionally very rich "pockets" have been encountered, as, e.g., on the Jumpers G.M., Simmer & Jack G.M., and the Geldenhuis Deep G.M. The gold is generally associated with quartz, pyrite, and in much less amount, chalcopryite. The very rich occurrence met with in the Jumpers G.M. in 1908 is worthy of description.

It was struck in the 3rd level between the Main Reef and the Main Reef Leader, and was partly in contact with a fine-grained dyke of basic composition. Its dimensions were roughly 10' x 10' x 10". The mineral contents, besides the gold, were mainly quartz, pyrite, and apatite. Of the latter mineral the writer is not acquainted with any other occurrence in veins in the Witwatersrand System. It is grey in colour and occurs frequently as distinct hexagonal crystals averaging about six millimetersⁱⁿ diameter, though some are much larger. The quartz and pyrite are moulded on the apatite. The gold, which was evidently late in order of precipitation, occurs as coarse hackly masses and also as layers along cracks in the quartz and pyrite, as well as along the cleavage cracks of the apatite. The maximum gold content is reported to have been got where apatite or spongy

pyrite occurred in the vein. Another quartz vein in proximity to that just described is practically barren of gold.

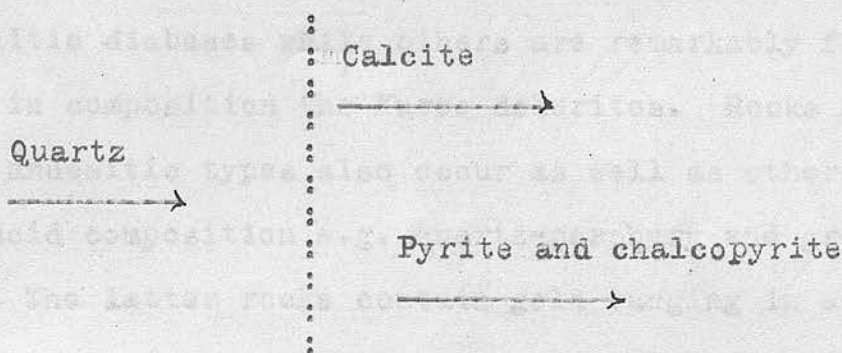
A very rich auriferous quartz vein encountered some years ago in the Simmer & Jack G.M. was about 200 feet from the nearest known dyke.

Veins traversing the Main Reef Series sometimes show signs of having been subjected to considerable movement enclosed cubes of pyrite being fractured and twisted out of shape, while massive sulphide occurrences are intensely sheared and rendered very friable.

Drusy cavities met with throughout the mines exhibit remarkable similarity in their mineral contents, and in the order of precipitation of the same. The minerals present are quartz, calcite, pyrite and chalcopyrite.

The quartz is always next to the walls, i.e., first in order of precipitation, and occurs as well-formed crystals of varying sizes. They may be quite clear or the inner and first formed portions may have a clouded or milky appearance, and occasionally beautiful "ghost quartz" crystals are found. On the top of many of the quartz crystals are crystals of calcite through which the former may project. The calcite is generally in flat rhombohedra ("nail-head spar"), and may be several inches in lateral diameter. Other faces may be present, and sometimes the crystals are of a very complicated character. Barrel-shaped crystals are not infrequent, and occasionally a crystal is found combining an acute rhombohedron with a scalenohedron. The cuboid is of rare occurrence. Pyrite and a subordinate amount of chalcopyrite is present in varying proportions. These sulphides are in small crystals, and their precipitation must in some cases have commenced before the precipitation of the calcite was completed and in such instances they are found in innumerable minute

crystals in the outer zone of the calcite crystals, giving that portion a greenish tint. The most of the sulphides lie on the ^{out}side of the crystals of calcite, as well as on such crystals of quartz as are not embedded in calcite; and they have very evidently ^{been} precipitated by preference on edges and corners of crystals. It is quite common to find the rhombohedral terminations wholly or partially covered by an aggregation of pyrite crystals. The general order of precipitation may be represented graphically thus:-



Films of pyrite are frequently found along the shear cracks of the blanket, and are especially conspicuous when passing through white quartz pebbles. In much rarer instances pyrrhotite occurs in the same way.

Mention might here be made of a very unusual occurrence met with in an open crack in the quartzite foot-wall parting of the Main Reef Leader in the Simmer & Jack G.M., viz., sphaerosiderite (concretionary siderite) on the top of which were scattered clumps of acute rhombohedra of siderite. This mineral was found just below the oxidised belt.

The veins, etc., described above are of varying ages. Some of the veins are sheared while others are unaffected by mechanical disturbances. Some are later than the basic intrusions, which they penetrate. Some, lying a -

long fault planes, show casts of the slickensides on the wall-rock. The nodules of marcasite or pyrite which are of comparatively late date are sometimes penetrated by veinlets of quartz. The films of pyrite in the shear cracks and the replacement by pyrite of the minerals of the late comparatively fresh type of basic intrusions show that pyritic solutions were permeating the rocks at a comparatively late date

ROCKS INTRU-
SIVE IN THE
MAIN REEF
SERIES.

Innumerable dykes and sills are intrusive in the Main Reef Series but comparatively little study has been given to them. The most common are of basic composition. Some of these are much altered and might be described as uraltic diabases while others are remarkably fresh, resembling in composition the Karoo dolerites. Rocks of dioritic and andesitic types also occur as well as others of distinctly acid composition e.g. quartz-porphyry and granite-porphyry. The latter rocks contain gold ranging in amount from a trace to 5 dwts. to the ton. Visible gold has been got in a much decomposed basic rock in the Ferreira G.M., but this has doubtless been introduced from without. Pyrite and other sulphides in crystals and irregular patches are of frequent occurrence in all the intrusive rocks.

THE ORIGIN OF
THE GOLD IN
THE BANKET.

The following are the conceptions which the writer has formed in the course of the foregoing study of the banket regarding the much vexed question of the origin of the gold. Of course this cannot be considered by itself, but only as part of the general problem presented by the mineralisation of the banket.

The dominant feature in the metamorphism of the banket, using the term "metamorphism" in its most general sense, is silicification, or the filling up of the pores in the original rock by quartz, and this, we may take it, was one of the earliest changes which the banket underwent. The

outlines of the pebbles are in general still maintained, but the same cannot be said of the smaller quartz grains which partly filled the interstices between the pebbles. These have undergone partial recrystallisation. This process however has been more active in some places than at others. The recrystallisation of quartz in the matrix may be regarded as subsequent to the initial silicification.

The pyritisation of the banket presents a very difficult problem. The pyrite occurs in two distinct forms easily distinguishable and essentially different in mode and date of origin. They may be termed respectively the first and the second generation of pyrite.

The first generation of pyrite is made up of grains about 0.1 mm. in average diameter, and rounded in outline. Generally speaking their shape is independent of the surrounding minerals. Becker and others regard these grains as alluvial and owing their forms to attrition, and in support of this Becker stated that he had observed such grains in the unoxidised banket with a coating of iron oxide. This observation has never been repeated, and it seems possible that the material seen surrounding the pyrite was a granular aggregate of rutile, which at first sight might easily be taken for limonite. It seems unlikely that so brittle and easily oxidisable a mineral as pyrite could be deposited in enormous quantity as rounded and unaltered grains among marine gravels. Certainly no parallel can be found in modern placers. Gregory supposes that they are pseudomorphous after grains of magnetite with some titaniferous iron ore. This seems possible, though it is difficult to believe that the large amount of sulphur necessary for the reaction could be derived from the decomposition of "some organic matter" in the beds, as Gregory suggests. In the case of a mineral

like pyrite, which occurs commonly in concretionary forms, it cannot be safely postulated that a rounded shape must be due to attrition. Many of the larger nodules of marcasite or pyrite which the writer has described from the Battery Reef might be mistaken for pebbles, judging from their form alone. Sometimes, it is true, the surface of these is rough with projecting edges and corners of crystals, but at other times they are perfectly smooth. Nor would the internal structure of the iron sulphide serve for discrimination, on account of the great variation to be observed. Sometimes the nodules are coarse-grained, sometimes fine-grained, and only occasionally is there any radially fibrous structure present. These nodules, though of metasomatic origin, do not owe their shape to pseudomorphism. In short, the minute rounded grains of pyrite in the banket may be pseudomorphous after some detrital mineral, but if so, it is more probable that the sulphur necessary for this transformation was furnished by percolating waters, from an outside source, than from organic matter in the beds themselves, or they may have been precipitated from solution in their present form along with the interstitial secondary quartz. That the date of the introduction of this generation of pyrite was early, is shown by the circumstances that only in very exceptional cases are rounded grains moulded on secondary minerals like chloritoid or tourmaline. That they have not been formed by replacement of quartz is indicated by the fact that they do not encroach on the pebbles, but are confined to the matrix.

The second generation of pyrite is of metasomatic origin, being a replacement of quartz. It is frequently conspicuous in hand specimens, appearing usually as irregularly shaped patches, though it is much oftener observable on examining microscopic sections of the rock. It may be

said generally that where there is a departure from the orderly arrangement of the pyrite, or where it exhibits crystalline outlines, microscopic examination reveals that it belongs to the second metasomatic generation. Nodular bodies of pyrite or marcasite must also be placed in this division. The proofs of the mode of origin which the writer has assigned to the second generation of pyrite have already been fully discussed, but may be stated generally as consisting in the moulding of pyrite on primary and secondary minerals with the exception of quartz, and in its encroaching on the quartz of the pebbles. The moulding of the pyrite of this generation on chloritoid is especially conspicuous, and that some time intervened between the formation of chloritoid and that of the pyrite is shown by the fact that frequently the former mineral has been partially replaced by quartz before the latter appeared. The second generation of pyrite need not have been formed all at the same period.

Becker, Gregory, and other alluvialists account for the occurrence of pyrite with crystal outlines by assuming a certain amount of crystallisation of the rounded pyrite, but no explanation so simple as this is admissible in view of the facts just stated. If, for the moment, we assume that the source of the second generation of pyrite was the banket itself, we must suppose that late in the history of the rock, long after complete silicification and subsequent to the production of chloritoid and other secondary minerals, the pyrite was to a considerable extent taken into solution, its place being taken by some other mineral, and thereafter transported a greater or less distance, and finally precipitated at the expense of quartz where we now find it. There remains in the banket no proof of any such widespread solution of pyrite, and certainly if there exist indications pointing to other more obvious sources of the second generation of

pyrite there is no good reason for supposing that the process above described ever took place to any great extent.

Other sulphides of late metasomatic origin occur in the banket with more or less the same relations to the other minerals of the rock as the second generation of pyrite. These sulphides are mainly pyrrhotite, chalcopyrite, sphalerite and galena. In many instances the occurrence of these minerals is clearly related to basic intrusions, and the appearance of such minerals in the pannings may be looked upon as indicating approach towards one of the intrusions mentioned. Doubtless some of the second generation of pyrite has had the same source. Gregory would seemingly explain the occurrence of identical minerals in the quartz veins by supposing that they have been leached from the adjacent conglomerates, but it is obvious that they may have had, in whole or in part, the same source as in the banket.

The gold visible in microscopic sections occurs in irregular forms and as crystals. Minute films are met with but no alluvial flakes. In fact the gold occurs in the banket in the same forms as in quartz veins. Coarse gold, such as is met with in microscopic sections cut from rich specimens of banket is generally associated with the second generation of pyrite, though not necessarily in contact with the same. It occurs within and also coating the nodules of iron sulphide. Sericitisation of the matrix and pebbles is sometimes specially marked in rich specimens of banket. In several such specimens from different reefs the writer observed an abnormal amount of secondary tourmaline, and in each case some of the gold was closely associated with that mineral. Coarse gold is sometimes associated with carbon.

Gold may occur in distinct shoots. This has been frequently denied and will probably remain a subject of dispute, until some attempt is made to systematise the vast num-

ber of data, contained in the mine assay plans, of the distribution of the gold - a very laborious task. The most convincing instance of a shoot that has come to the writer's knowledge is in the Simmer & Jack G.M., or rather was, for it is now worked out. It consisted of a belt in the South Reef Leader containing an abnormal quantity of gold, much of it visible to the naked eye. It was about 20 feet wide and defined by a series of strongly marked vertical joints. It ran for a distance of about 300 feet.

It would appear that the gold in the banket is of two distinct generations, corresponding more or less to those of the pyrite, though as in the case of the latter mineral, it need not follow that the gold of the second generation is all of the same date or from an identical source, but merely that it was introduced at a much later and essentially different stage in the evolution of the rock.

The gold of the first generation is in general finer, and has a wider and more uniform distribution than the second generation. It was probably precipitated with the first generation of pyrite during the silicification of the banket, while the rock still retained^{ed} its porous character. Here the question arises why this precipitation was confined so much to certain beds in one horizon. It is impossible to account for this by assuming that the beds selected were more permeable to solutions than others. There is no good reason for believing that the conglomerates of the Main Reef Series differed in porosity from those at other horizons of the Witwatersrand System. The presence of pyrite and gold in the pyritic layers of the banded pyritic quartzite is conclusive evidence against any theory of the mineralisation of the banket based on differences in porosity.

The pyritic layers just mentioned are identical in composition with the matrix of the banket, and differ from the surrounding barren quartzite not only in the secondary minerals present, but also in containing, e.g., the relatively heavy primary mineral, chromite. There can be little doubt that the presence of pyrite and gold in the banket and pyritic quartzite is primarily due to the original mineral composition. Either gold alone or pyrite and gold were among the original constituents of the beds, or pyrite or both minerals were subsequently precipitated from solution through the influence of a heavy primary mineral. I have already referred to arguments that tell against the supposition that either gold or pyrite were original constituents of the banket, and I might add to those the improbability that the quartz reefs of the older rocks, which are generally regarded by alluvialists as the source of the gold, and which were contributing material to the Witwatersrand beds throughout the course of their deposition, should during one comparatively brief period shed over a vast area so enormous a quantity of gold or of pyrite.

The Witwatersrand area must, during the deposition of the system, have been slowly subsiding, as evidences of shallow water conditions are apparent throughout. On the adjacent land area quartzites and banded slate were exposed, as is shown by the presence of pebbles of these rocks in the banket; and the presence of chromite in the matrix of that rock and in the pyritic quartzite suggests that, during the deposition of at least the Main Reef Series, ultrabasic rocks of the Swaziland System were also contributing the products of their disintegration to the Witwatersrand sea. Now in an area of subsidence with a slowly encroaching sea, it is easily conceivable that the rocks principally contributing to

the sediments would vary considerably at different periods. This would be a sufficient explanation of the restriction of a heavy mineral, capable of bringing about the precipitation of pyrite and gold from solution, to one horizon in the sediments. This mineral, too, would not necessarily be uniformly distributed throughout the beds of that horizon, but would vary considerably in amount from place to place, as happens in the case of chromite. That the precipitant, if any, was a heavy mineral is obvious when one reflects on the fact that it must have been confined to the pebbly beds, and to clearly defined layers in the accompanying sand, the latter occurrence corresponding to the well-known heavy "black sands" found in beach or shallow water deposits. With regard to the identity of this hypothetical precipitant mineral, there is something to be said for Gregory's surmise that it may have been ironstone, possibly titaniferous. Rudely spherical and irregular aggregates of secondary rutile are a conspicuous and invariable concomitant of pyrite, both in the banket and the pyritic quartzite, and may be a product of the decomposition of some previously existing widespread mineral. The hypothesis of the presence among the original constituents of the banket of a heavy mineral which acted as a precipitant of gold explains those features in the distribution of that metal in the banket that seem to point to the alluvial origin of the gold.

The solutions from which the gold and pyrite of the first generation were precipitated would be able to permeate the still highly porous beds in every direction, though the relative proportions precipitated of the two minerals might, owing to local differences in the nature of the solutions or of the precipitant, vary considerably.

The second generation of gold, with that of pyrite, was introduced after the banket was consolidated and

had been subjected to the dynamic influences that produced the chloritoid, which is so abundant in the rock. The percolation of the auriferous solutions must therefore have been slow, and the areas affected limited to those nearest the source of the solutions, or that afforded the readiest access. This generation of gold is therefore very erratic in its distribution and has been impressed, as it were, in patches or shoots on the top of the earlier and more uniformly distributed generation. The presence of the first generation of pyrite and gold would influence the precipitation of the second. It is not to be assumed that because metasomatic pyrite of the second generation is a very frequent associate of coarse gold that the reverse is true and the presence of this pyrite is necessarily an indication of high gold content, for this is not the case.

The association of gold in certain localities with carbon adds to the complexity of the problem. It is evident from the distribution of the carbon that much of it at least, whatever be its origin, came into its present position late in the history of the rock, and the associated coarse gold must be of equally late date. That it acted as a precipitant of gold there can be no doubt, though the suggestion that it constituted the precipitant of gold in the banket cannot be seriously entertained.

We come now to the question of the probable source or sources of the gold.

According to the theory just stated there must have existed two or more widely separated periods during which auriferous solutions entered the rocks in quantity. That, with respect to the Transvaal area, two such periods existed is a corollary even from the placer theory of the banket, in this case one previous to the deposition of the

Witwatersrand System, and another, necessitated by the presence of auriferous veins in the Black Reef, Dolomite and Pretoria series, after the laying down of the Transvaal System.

The numerous basic^{dykes} and sills, which intersect the Main Reef Series, have naturally been regarded as a possible agency through which the gold has been introduced, but the evidence on this point is at present of the most conflicting character. However, the probable cause of this is not far to seek. Notwithstanding all the attention that has been directed to the Witwatersrand Goldfield, the basic intrusives have never been scientifically studied. Their relative ages have never been made out. All that is known in this connection is that there were at least two widely separated periods during which basic intrusions occurred; but there may have been more than two. It might very well happen that the intrusives of one period were a source of auriferous solutions, while those of another were not. To add to the confusion, some of the bodies of rock regarded on the mines as igneous are of sedimentary origin. Accordingly the most judicious attitude to adopt towards this question is to suspend judgment until the tangle has been unravelled; though there would appear to be no doubt that in certain instances, like that described by Truscott (15) from the Worcester G.M., a relation exists between basic intrusives and the gold content of the reefs. The apparent enrichment of the banket on one side of a basic dyke and not on the other, a circumstance occasionally met with, suggests that in some instances the dykes may have affected the gold content of the banket indirectly, by exercising a directional influence on the cir -

(15) "The Witwatersrand Goldfields" (London), 3rd. edition, 1907, p.111.

culatation of percolating waters.

Mr. M. Weber (16) has recently described the extensive occurrence of acid intrusives, viz., Quartz-porphyrries and granite-porphyrries in the Witwatersrand System, and by doing so he introduced a fresh element into the discussion of the origin of the gold in the banket. His study of these rocks is not complete, but so far as at present known, they are found in the Lower Witwatersrand Series not far below the Main Reef Series, and at places they cut through the latter series or lie almost immediately beneath it. The fresh igneous rock contains gold ranging from a trace to 5 dwts. per ton. Mention has already been made of the occurrence of an unusual amount of sericite and tourmaline in some very rich specimens of banket,. From the consideration of the foregoing and the evidence in other parts of the world pointing to the conclusion that auriferous solutions most frequently emanate from acid and intermediate magmas, the writer thinks it probable that the acid intrusives are the original source of some of the gold in the Main Reef Series.

(16) Trans. Geol. Soc. S.A., 17th May 1909, pp. 67-77.

EXPLANATION of PLATES.

- Fig. 1. Banket, unoxidised. The narrow band of quartzite on the right indicates the direction of bedding. Robinson Deep G.M. Diam. x $2/3$.
- Fig. 2. Banket, oxidised. Princess Estate G.M. Diam. x $\frac{3}{8}$.
- Fig. 3. Banket, showing pebble of "banded ironstone". Geduld G.M. Diam x $2/3$.
- Fig. 4. Exceptionally large pebbles of quartzite and vein-quartz from the banket, showing the prevailing muffin-like form. Luipaards Vlei Estate G.M. etc. Diam. x $1/15$.
- Fig. 5. Banket containing a pyritic nodule, which has partly replaced a vein-quartz pebble (q.p.) and enclosing to the right a portion of the sericitic border (s.) of the pebble. Battery Reef Leader, Lancaster West G.M. Diam. x 31; nicols crossed.
- Fig. 6. Banket showing part of two pyritic nodules with a development of fibrous quartz at the acute terminations; from the same locality. Diam. x 17; nicols crossed.
- Fig. 7. Quartzite partially replaced by pyritic crystals and veinlets (second generation of pyrite) Rose Deep G.M. Diam. x 20.
- Fig. 8. A clump of chloritoid crystals (ce.) in the interstices of which pyrite (second generation) has replaced quartz. Battery Reef Leader, Lancaster West G.M. Diam. x 78.
- Fig. 9. Banket showing, above to the right, portion of a pebble of quartz-tourmaline rock, on the lower margin of which a few crystals of pyrite (p.) have replaced the quartz (q.). (t) indicates tourmaline,

Main Reef, Geldenhuis Main Reef G.M. Diam. x 87.

Fig. 10. Banket showing a vein-quartz pebble (q.p.) partially replaced by fine-grained quartz, chalcedony and pyrite; also a subsequent replacement of the two first mentioned minerals, by an amoeba-like aggregate of pyrrhotite (ph). The grains of pyrite enclosed in the pyrrhotite cannot be seen in the photograph. South Reef, Roodepoort Central Deep G.M. Diam. x 17; nicols crossed.

Fig. 11. Partially calcified banket, showing portions of two vein-quartz pebbles. One occupying the right top half of the photograph is considerably altered to calcite (Ca), within which mineral there still remain some remnants of the original quartz (q). The other to the left at the bottom is replaced round its margin by chlorite and sericite. Between the two pebbles is a portion of the matrix of the banket now composed of calcite, chlorite, sericite and pyrite. Meyer & Charlton G.M. Diam x 18; nicols crossed.

Fig. 12. Banket in which quartz (q) is being replaced by chlorite (c). Princess Estate G.M. Diam. x 33.

Fig. 13. Marginal portion of pyritic nodule showing the gradual replacement of quartz grains (q) and a border of fibrous quartz (f.s.). Battery Reef Leader, Lancaster West G.M. Diam. x 17; nicols crossed.

Fig. 14. Portion of marginal zone of pyritic nodule showing replacement of quartz and envelopment of chloritoid crystals. Same locality. Diam. x 78.

Fig. 15. Transverse section of fibrous quartz bordering a pyritic nodule, Same locality. Diam. x 162.

- Fig. 16. Banket containing a pyritic nodule which has wholly or partially enclosed chloritoid crystals during its growth. Same locality. Diam. x 32.
- Fig. 17. First generation of pyrite in rounded grains. West Reef Porges Randfontein G.M. Diam. x 30.
- Fig. 18. Chloritoid moulded on first generation of pyrite and on zircon. Main Reef, Robinson G.M. Diam. x 75.
- Fig. 19. Second generation of pyrite moulded on chloritoid. Main Reef, Windsor G.M. Diam. x 30.
- Fig. 20. Second generation of pyrite moulded on chloritoid and zircon. Banded pyritic quartzite, Meyer & Charlton G.M. Diam x 78.
- Fig. 21. Second generation of pyrite, well crystallised, moulded on zircon. Main Reef, Geldenhuis Main Reef G.M. Diam. x 72.
- Fig. 22. Much chloritised banket, with pyrite well crystallised, from near contact^q basic dyke. Main Reef Leader, Robinson Deep G.M. Diam. x 90.
- Fig. 23. Tourmaline moulded on chloritoid, subsequent to partial replacement of the latter by quartz. Main Reef, Robinson G.M. Diam. x 100.
- Fig. 24. Crystal of gold, octahedral faces predominant, in quartz grain, and connected with the exterior of the grain by chlorite; also irregular^{grains} of gold. Randfontein Leader. Porges Randfontein G.M. Diam. x 200.
- g = gold, c = chlorite, q = quartz, m = muscovite.
closely
- Fig. 25. Gold associated with tourmaline. South Reef, Ferreira Deep G.M. Diam. x 77.
- Dotted arrows indicate gold.
- Unbroken arrows indicate tourmaline.
- Fig. 26. Gold associated with tourmaline. Main Reef. Diam. x 90.

Dotted arrows indicate gold.

Unbroken arrows indicates tourmaline.

Fig. 27. Rich banket, showing gold and much sericite.

Botha's Reef, Lancaster West G.M. Diam. x 74;
nicols crossed. Arrows indicate gold.

Fig. 28. Rich banket showing intense sericitisation. Though gold is not visible in the photograph, much^{of} it can be seen in the same micro-section. Diam. x 11; nicols crossed. The dark irregular grain is quartz which is being replaced by sericite (indicated by arrows).

Fig. 2.



Fig. 4.

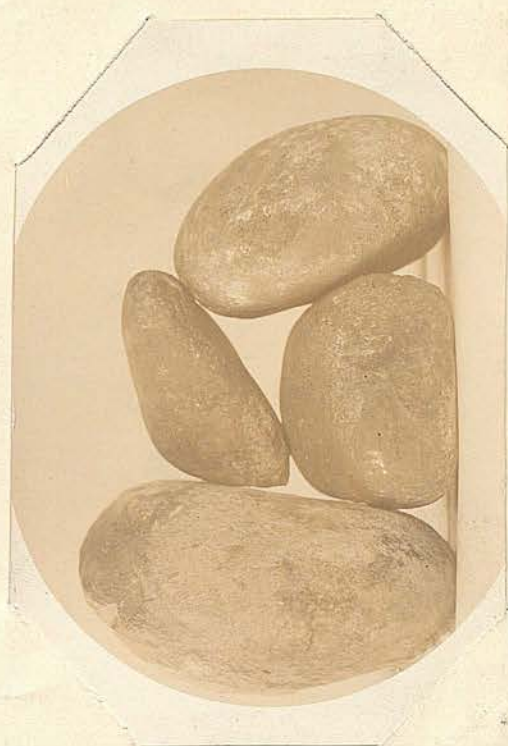


Fig. 3.



Fig. 1.



Figure 5

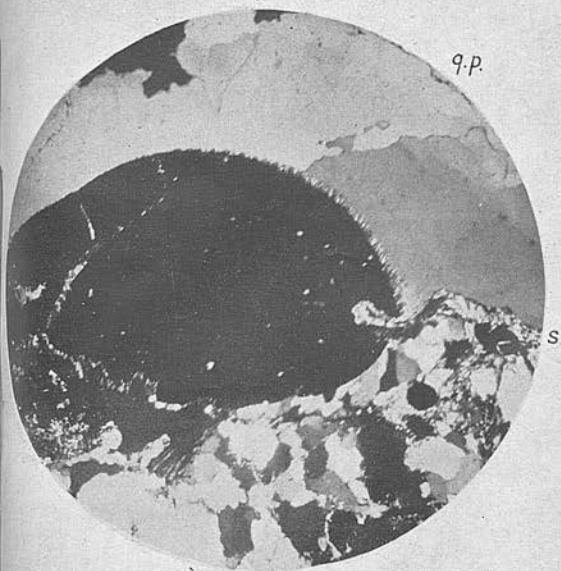


Figure 6

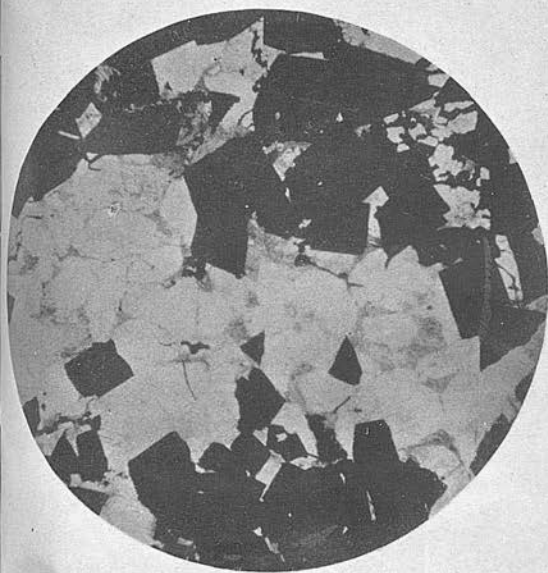
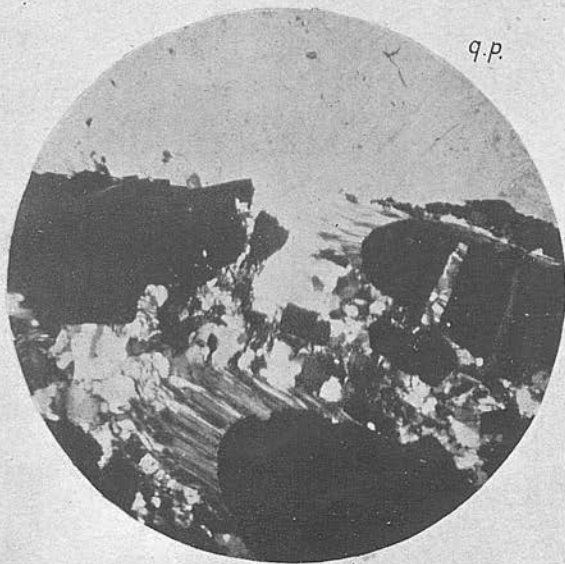


Figure 7

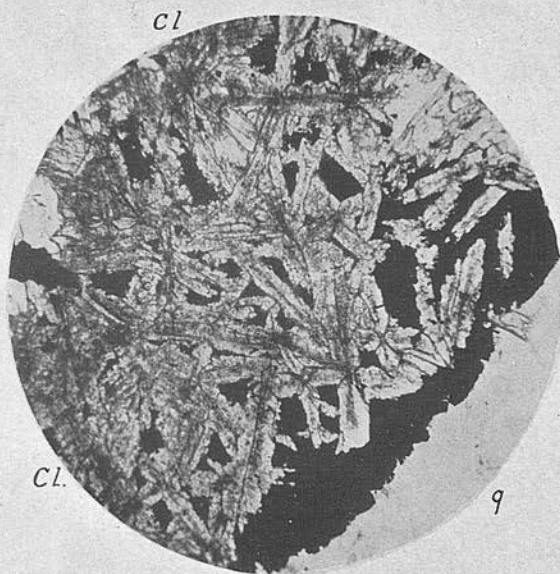


Figure 8

Figure 9

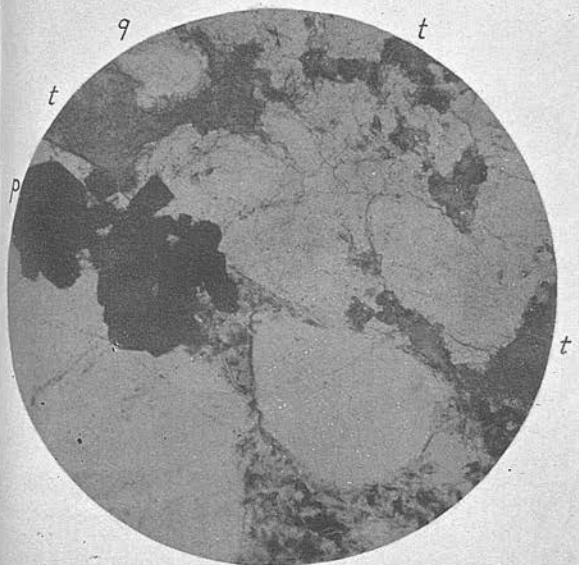


Figure 10

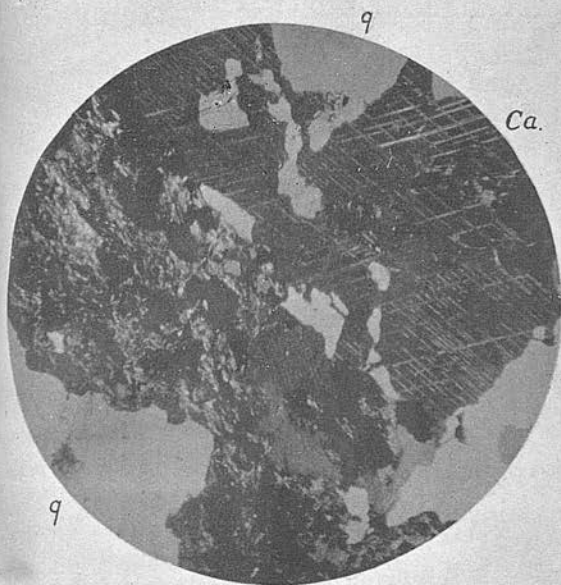
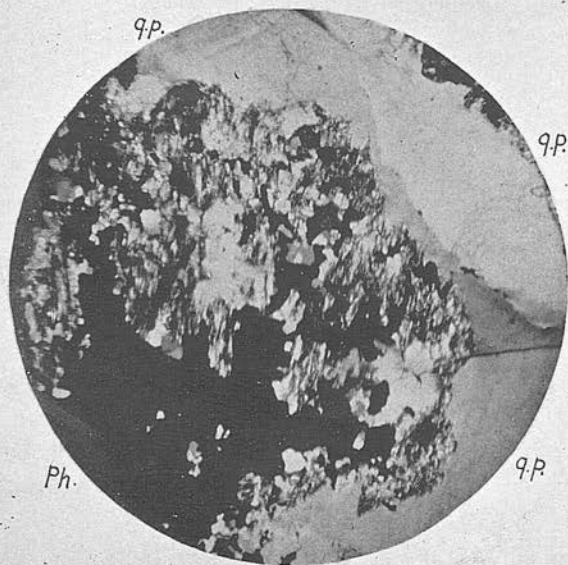


Figure 11

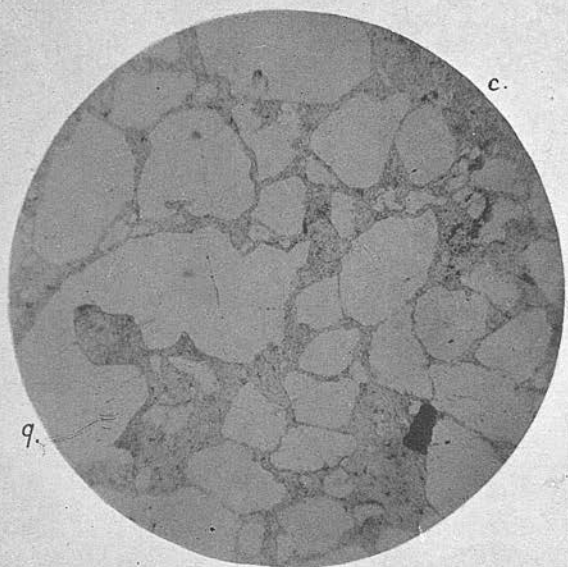


Figure 12

Figure 13

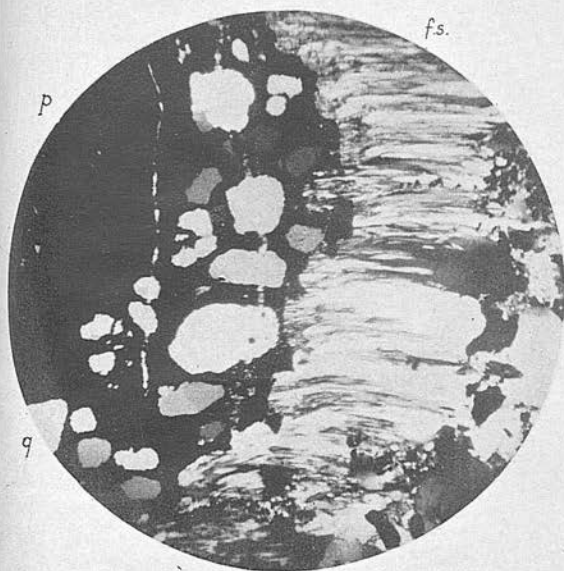


Figure 14

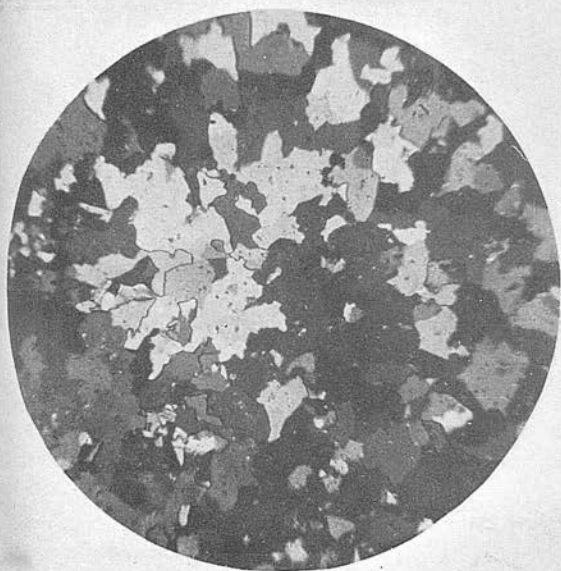
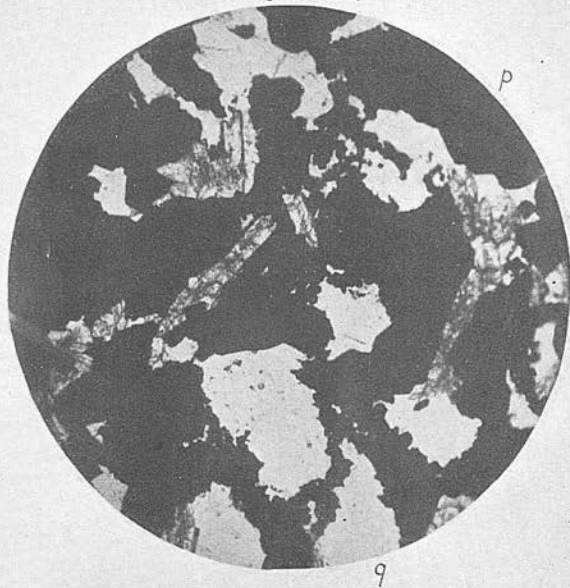


Figure 15



Figure 16

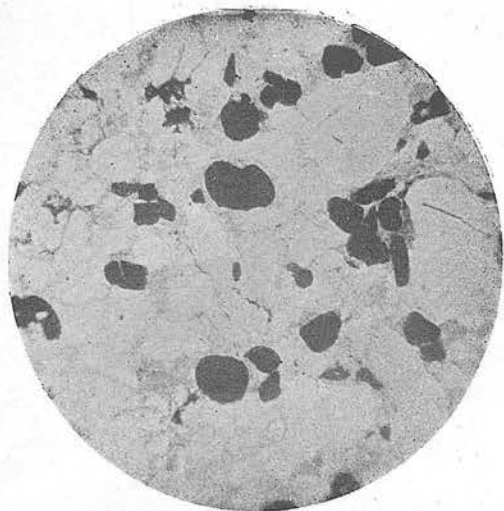


Fig. 17

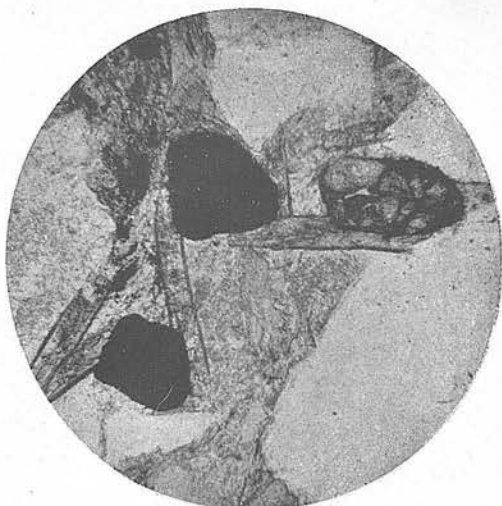


Fig. 2. 18

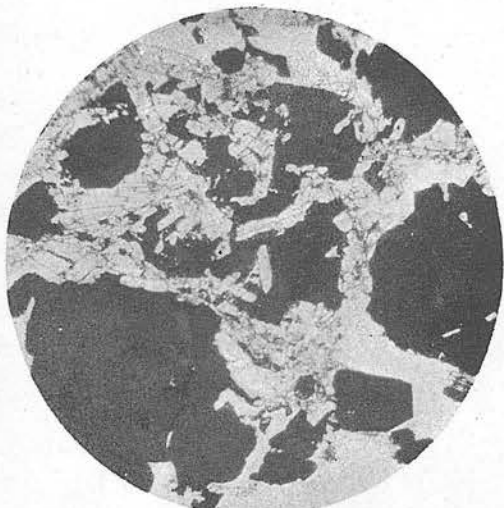


Fig. 3. 19

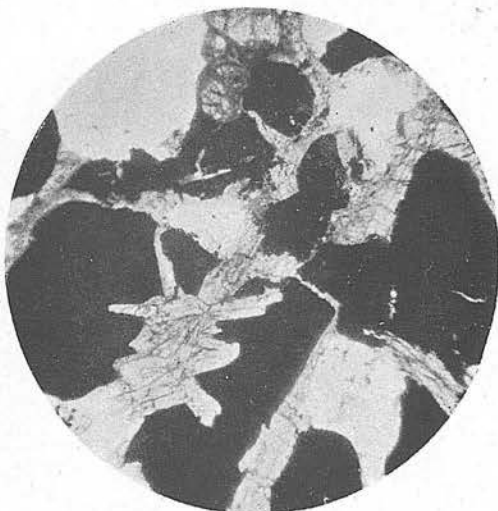


Fig. 4. 20

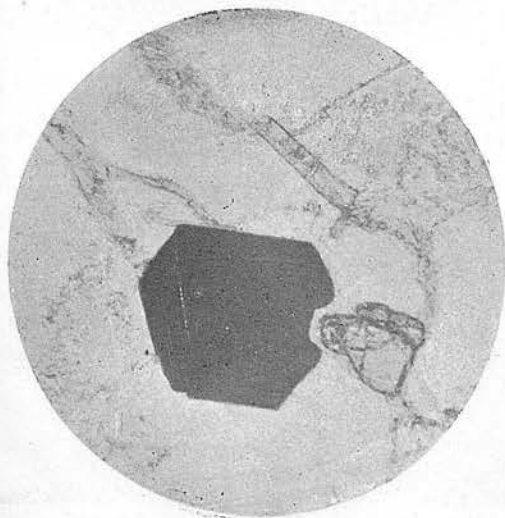


Fig. 5. 21

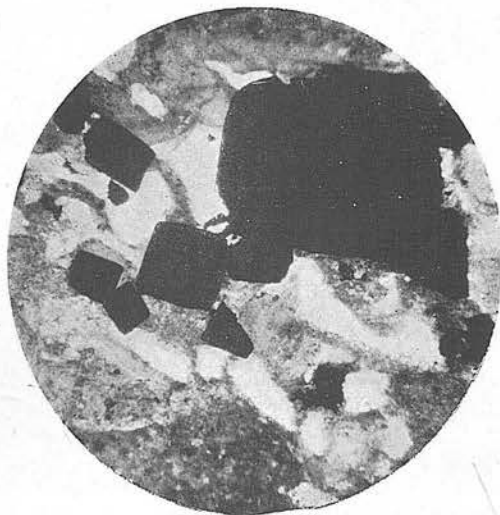


Fig. 6. 22

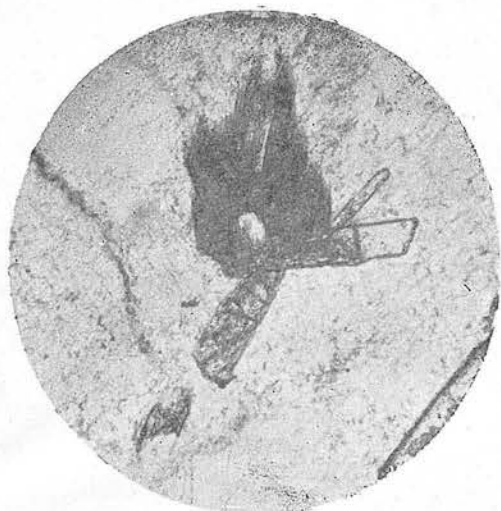


Fig. 23

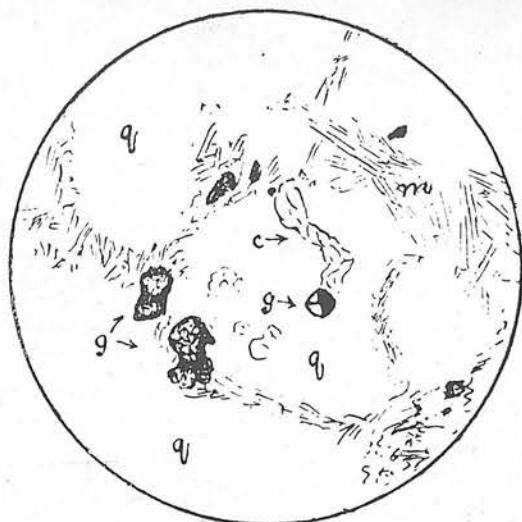


Fig. 24

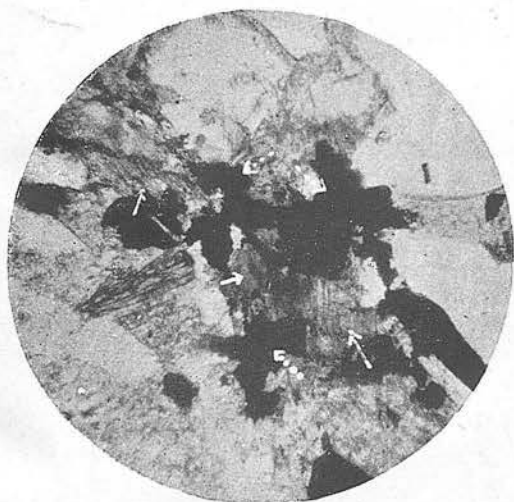


Fig. 25

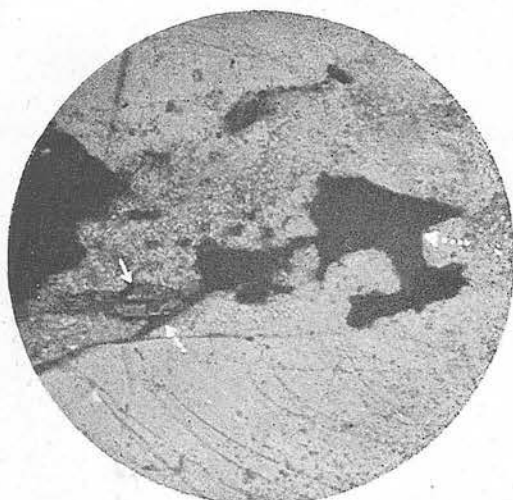


Fig. #26

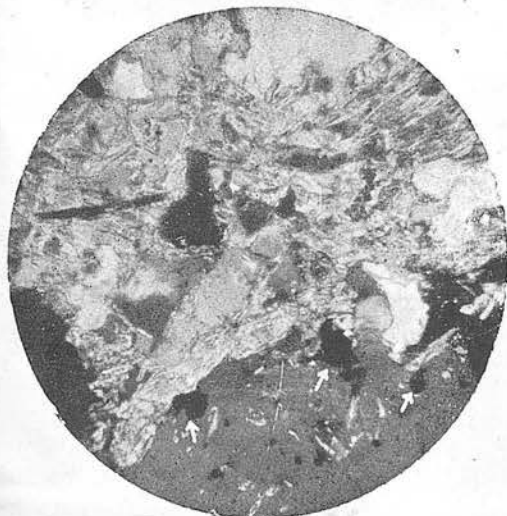


Fig. 27



Fig. 28